# NSF Proposal 2001

# Project Summary

The Experimental Particle Physics group at Northeastern University has developed a long-range, well-phased program of particle physics research at the world's highest available energies. This program involves experiments at the following facilities: the LEP $e^+e^-$ collider at CERN, the Tevatron $p\overline{p}$ collider at FNAL, the LHC $pp$ collider at CERN, and the Pierre Auger Observatory (PAO) in Argentina. Research at these laboratories is handled by large international collaborations of hundreds of physicists who assemble complex detectors and associated software in order to perform experiments whose lifetimes extend over decades. These experiments are essential for the study of the particles and forces that existed in the very early universe and which hold the key to our understanding of nature.

This proposal summarizes the ongoing work of the group under NSF award PHY-9972170, and requests funding of approximately $840k per year for the next three years. This will help support the work of a group of 27 people, with five faculty (Alverson, Reucroft, Swain, von Goeler and Wood), six postdoctoral associates (two at CERN, two at FNAL and two at Northeastern) three graduate students and approximately five undergraduate and high-school students. The group also has four technical physicists, three software engineers and an administrator whose salaries and expenses come mostly from either the university or other NSF awards.

During the previous grant period we have continued our active roles in the collider experiments L3 at CERN and DØ at FNAL, as described in sections 2.1 and 2.2 respectively, as well as making significant contributions to data analysis techniques and computing. We have continued to prepare for the LHC era by taking on important leadership, instrumentation, and software tasks within the CMS collaboration, as described in section 2.3. We have also developed an active program of research into ultra-high energy cosmic ray astrophysics, making major contributions to the software for the PAO.

Both the L3 and DØ experiments are immensely rich sources of physics. In the past three years L3 has published more than one hundred physics papers [1], as well as a dozen or so papers combining results of the four LEP collaborations. DØ has published almost fifty papers papers [2] in the same three years, based on Run 1 data. We have made significant contributions to a number of these papers. In addition we have numerous technical and phenomenological papers with small numbers of authors. For clarity, our bibliography is restricted to contain only papers which have a *major contribution* from the Northeastern group *during the last three years*.

In the next grant period, Reucroft will continue to oversee the global activities of the group. He is primarily involved in CMS, but also makes contributions to DØ and PAO. Swain is concentrating on PAO, but also has significant CMS responsibilities at CERN. Wood will continue to coordinate DØ activities at FNAL. Swain and Wood are the two youngest faculty members in the group and their complementary roles in the different components of our research program are crucial to the overall dynamics of the group. We are planning to hire a junior faculty member during the next three years. We are open-minded regarding the research activities of this new person, but we will give top priority to those who consider CMS their primary research activity. The other senior personnel involved are: Alverson, who will continue to work on graphics software, primarily for DØ but with applications in CMS and PAO; Taylor, who will continue with his leadership role in CMS computing and software; and von Goeler, who will continue his development work for the CMS muon alignment system; their vitae are included in this proposal.

The physics activities of the group in the recent past have concentrated on electroweak physics with complementary analyses taking place at L3 and DØ. These have included first and best determinations of a wide range of anomalous couplings of electroweak bosons to third generation fermions and among themselves. The group plans to continue to work within this framework in the proposed grant period, taking advantage of the new data to come from Run 2 with the upgraded DØ detector. The group also plans to continue searches for processes which are either rare or forbidden in the Standard Model. Hardware and software activities are also concentrated in areas in which the group has long-standing expertise, and involvement in the proposed grant period is a natural continuation of the established track record with photodetectors, muon chambers, and software and computing. Interdisciplinary and outreach activities developed dramatically during the previous two grant periods, and the group looks forward to continuing and expanding on this work with future NSF support.

# Project Description

The goal of the group is to investigate the structure of matter and the fundamental interactions at the highest energies. Our research program encompasses a broad range of activities, including hardware development, data analysis, an extensive outreach program, and planning for future experiments. In addition, we feel it is essential for our students to have meaningful experiences in running experiments and to be able to complete topical analyses for their theses. To accomplish these tasks and to be highly productive in a modestly sized group requires a careful research plan.

We are involved in three experiments which are strategically phased for the accomplishment of our goals. In recent years, we have extracted a great deal of physics from the L3 data at the $Z^0$ and from Run 1 of DØ at the Tevatron. We have finished collecting LEP2 data with L3, while simultaneously working on the detectors for the DØ upgrade and for CMS at the LHC. LEP data taking is now over and Run 2 is beginning. The Tevatron should provide us with rich data until the LHC turns on, while we continue to ramp up our activities on CMS. The PAO project is currently under construction with a small section of the full array already taking data.

We try to make the best use of our resources by working on similar topics on different experiments. For example, we have performed trilinear gauge coupling analyses at DØ, and at L3, and are studying them for CMS. Members of our group have developed common detector and event visualisation software for L3, DØ, CMS, and PAO, and we are involved with muon chamber calibration/alignment in both DØ and CMS.

In the following sections we describe our proposed research activities over the next three years, and review the results from previous NSF support.

## 1 Proposed Research Program

The proposed activities of the group during the coming grant period represent a carefully phased set of activities, each building on the others, and keeping us simultaneously involved with both data analysis and construction projects.

The L3 experiment at LEP has been enormously successful. The experiment is now over having run for a decade around the centre-of-mass energies for the production of millions of Z's (LEP 1) and later around and above the WW pair threshold (LEP 2). We do plan to continue working on analysis and finishing up with our responsibilities, but are not requesting any funding for these activities. DØ at Run 2 should provide a rich source of new physics, and additional upgrade activities are also planned. CMS will not take data during the coming grant period, but we have several major responsibilities which we plan to keep up, and will be well-placed to take maximum advantage of the data when it starts to come in 2006. Each of these activities is described in more detail in the following sections. PAO has already begun taking data with a relatively small "engineering array" and will continue to grow over the grant period, providing an ever-increasing supply of data as well.

### 1.1 DØ at the Tevatron

**Personnel** – Faculty: G. Alverson, S. Reucroft, D. Wood; Postdoctoral: N. Parashar, D. Shpakov ; Graduate Students: S. Doulas; Visiting scientist: I. Churin.

#### 1.1.1 DØ at Run 2a

The DØ experiment recently began its exciting data-taking phase with the upgraded Tevatron and Main Injector. The Northeastern group has been involved in the upgrade of the DØ muon system for Run 2a since 1995 (see section 2.2). We are currently busy with commissioning the systems we have helped to develop: the muon data acquisition system, the muon calibration, and the LED scintillator pulser. With the recent addition of Alverson, we are also involved in graphics for event display with the DØscan program.

#### 1.1.2 Physics with muons

High $p_t$, isolated muons are one of the cleanest signatures for high-$Q^2$ electroweak decays ($W \to \mu\nu$, $Z \to \mu\mu$, $t \to \mu\nu b$, ...), while muons in jets provide a useful tag for $b-$quark jets. The work of the Northeastern group on the DØ muon system in Run 1 and for Run 2 has provided us with invaluable expertise on the working of the muon system with applications to triggering, muon identification, and measurement. We plan to exploit this expertise to explore the rich physics potential of Run 2.

One of the channels we (Wood and Shpakov) are studying is $t\bar{t} \to \mu\nu +$ jets. We had a handful of such events in Run 1, but should have hundreds in Run 2. We are working with other groups on the measurement of the total production cross section for $t\bar{t}$, and we also intend to make a direct measurement of the top quark charge. The charge measurement requires a muon to tag the sign of the $b-$jet, along with a kinematic fit to associate the proper $b-$jet with the leptonic $W$ decay, and it requires a good understanding of muon efficiencies and sign measurements.

Parashar will be involved in Higgs searches for which di-bosons are significant backgrounds.

Doulas' thesis is a search for long-lived charged particles. One possible scenario for seeing such particles would be the existence of a nearly degenerate chargino and neutralino, where the neutralino is the LSP but the phase space for chargino decay is so small that it would live long enough to reach the muon system. Recent theories of supersymmetry breaking involving extra dimensions or gauge-mediation have provided additional motivation to search for a long-lived chargino. Such a particle could pass through all of the inner detectors and leave hits in the muon chambers and muon scintillators. It would appear to be a muon, but with a slower speed than one would expect for a muon of the same momentum. The time-of-flight measurement feature of the muon scintillators can thus be used to search for these particles. Doulas is the primary expert on the scintillator calibration system, and he is using this system to push the timing measurements to the highest possible precision. Some very recent data are shown in Fig.1, which give the timing distribution for particles hitting the inner layer of muon scintillators.

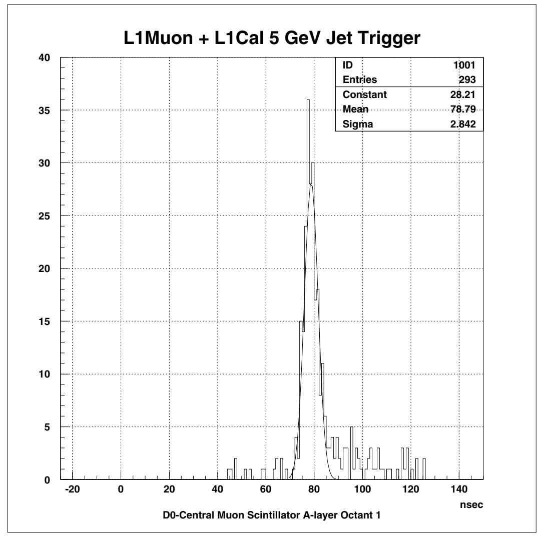


Figure 1: Time distribution from DØ muon scintillators in $\mu + jet$ triggers. The peak is from prompt muons.

A common feature of the analyses listed above is that the signal can be obtained with a $\mu$+jet trigger. This is not a coincidence, but rather is a strategy for addressing a range of physics topics while concentrating the group's efforts on a particular sample. A well-understood inclusive muon + jet sample can be used as a starting point for all of these measurements and searches, and others as well. There are many common studies that are needed for all of these physics channels: physics and detector backgrounds, muon identification efficiencies, trigger turn-ons, trigger exposure (integrated luminosity), and resolutions. The acceptance calculations, of course, depend on the particular channel that is being studied.

Northeastern's hardware and software components of the muon system are either complete or nearly complete, and the development activity will diminish as we get into more stable physics running in the coming months, and at the same time our data analysis efforts will increase. Nonetheless, the group is committed to maintaining and developing the data acquisition and calibration systems as needed and to support the muon system through shifts and ongoing monitoring.

### 1.1.3 DØ Scan

Alverson will continue his work on the DØScan event display program for which he is responsible. This will leverage future developments in IGUANA ( [3]) toolkit developed by the group primarily for CMS. The effort of continually extending DØScan and integrating new code developed at CMS will provide the vital second application required to develop software which can function as a true toolkit. Collaborators are already requesting changes and extensions to DØScan, either for detailed investigation of detector subsystems or to study particularly interesting events. We anticipate that this will continue through the life of the experiment. We will continue to maintain, document, and extend DØScan, including the work involved in Alverson's position as co-leader of the DØ graphics group.

### 1.1.4 DØ at Run 2b

Run 2 of the Tevatron was originally planned to deliver a total integrated luminosity of 2 fb$^{-1}$ per experiment. With additional accelerator techniques (an antiproton re-cycler ring, slip stacking in the booster, etc.) and a strong motivation to use the Tevatron to its fullest potential before LHC turns on, the laboratory now plans an extended "Run 2b" to bring the total integrated luminosity to 15 fb$^{-1}$. This opens up a number of very exciting possibilities for precision measurements and searches, most notably a real possibility to detect a Higgs boson up to a mass of 180 GeV. Discussions continue about possible additional accelerator upgrades that would provide 30 fb$^{-1}$.

The challenge of Run 2b is to run the detectors effectively at luminosities of approximately $5 \times 10^{32}$ cm$^{-2}$s$^{-1}$ (2.5 times higher than the Run 2a design luminosity), with a bunch spacing of 132 ns (instead of the current spacing of 396 ns). To compound this challenge, any upgrades to the detectors for Run 2b must be ready by the end of 2003 and be installed in situ in a short 6-month shutdown.

A robust trigger is the cornerstone of a hadron collider experiment. Aside from the replacement of the silicon microstrip detector, the largest change needed for DØ for Run 2 is an upgrade of the trigger system. While parts of the trigger system (the muon trigger, for example) are expected to be able to handle the higher luminosity and shorter bunch spacing, other parts (calorimeter jet triggers, for example) will start to fail.

Of the three levels of triggering in the DØ experiment, the Level 1 trigger is particularly constrained. It must pipeline information from the detector subsystems and examine every collision and deliver a trigger decision with a latency of only about 3 microseconds. It must reduce the event rate from the collision rate of about 7 MHz to an output rate of no more that 5 kHz. The limitations to the output rate are deeply embedded in the readout electronics, so the goal for Run 2b is to increase the rejection by a factor of 2.5 without compromising the trigger efficiency.

Much of the triggering for Run 2b is expected to be based on jets. For example, we would like to be able to trigger on the Higgs channel $ZH \rightarrow \nu\bar{\nu}b\bar{b}$. In the Level 2 trigger, it should be possible to trigger on the displaced vertices of the $b$-jets, but at Level 1, the only available trigger objects are the two acoplanar jets. The current Level 1 trigger can only count the number of $\Delta\eta \times \Delta\phi = 0.2 \times 0.2$ trigger towers in the calorimeter above a given threshold, and would not give sufficient rejection against the abundant QCD 2-jet background. One would like to be able to count actual jets instead of small towers, and to have the ability to apply topological cuts. The full scope and strategy of the Level 1 upgrade is only now being determined, but it might include digital filtering of the calorimeter signals to identify the correct beam crossing, implementation of jet-finding algorithms (currently done at trigger level 2) in FPGA's (Field Programmable Gate Arrays) in the level 1 calorimeter trigger, finer segmentation in the track trigger, and azimuthal matching between tracks and electromagnetic clusters in the calorimeter.

We have recently joined the nascent effort to upgrade the Level 1 trigger. Wood has taken on the responsibility of project manager for this upgrade (together with Prof. Hal Evans from Columbia University), and we anticipate that this will be a substantial activity over the period of this grant.

## 1.2 CMS at the LHC

**Personnel** – Faculty: S. Reucroft, J. Swain, E. von Goeler; Postdoctoral and Technical: L. Taylor, A. Kuznetsov, J. Macleod, J. Moromisato, Y. Musienko, I. Osborne, R.Terry, L. Tuura.

### 1.2.1 ECAL Readout

One of the main design goals of the CMS detector is to provide excellent electromagnetic calorimetry in order to measure electrons and photons with great precision. Aside from the fact that these particles are among our cleanest probes of fundamental physics, the ECAL has an especially significant role in searches for relatively low mass Higgs bosons. In the mass range currently favoured by fits to electroweak data and the results of direct searches for a Higgs boson, the most likely channel for Higgs discovery is via its decay into two photons. These photons will be detected and measured in the ECAL, and excellent performance will be required to quickly discover or rule out a minimal Higgs boson. Almost all other searches for new physics also require good electromagnetic calorimetry, as electrons and photons provide two of our cleanest and best-understood probes of high energy interactions.

The CMS ECAL barrel is made of some 62,000 crystals of lead tungstate, each of which is read out by two avalanche photodiodes (APD's) packaged together as a single until. APD's are relatively new devices which offer significant advantages over other photodetectors, and we have pioneered their application in high energy physics since the days of the SSC.

Our group has demonstrated for the first time the APD's ability to provide gain in strong magnetic fields [4]. Even more importantly, we were able to show that suitably manufactured APD's could survive the sort of intense radiation environments [5, 6] expected at CMS.

Swain is US CMS level 3 manager responsible for the APD's and we plan to continue our ECAL commitments through the construction phase of the experiment, ensuring that the APD's are properly characterized and tested, as described below.

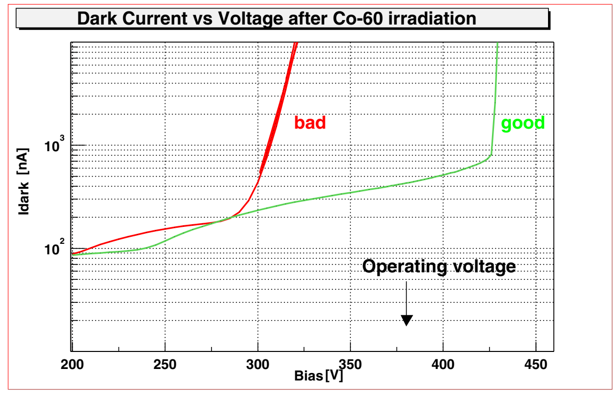


Figure 2: APD dark current as a function of voltage following irradiation with $^{60}$Co. APD's unsuitable for use in CMS reveal themselves via a dramatic increase in dark current making them completely unusable at the required operating voltage.

### APD Characterization and Quality Control

Despite being two-terminal devices, APD's are remarkably subtle devices with a wide range of properties that must be understood throughout the lifetime of the CMS experiment. These include the dependence of parameters such as gain and dark current on voltage, temperature and irradiation, as well as the behaviour of various noise parameters. It cannot be over-emphasised that once the CMS ECAL is completed, there is no foreseeable way to replace APD's which fail or become so noisy as to interfere with trigger decisions. In this respect, the ECAL construction is much like sending an experiment into orbit, and careful quality control is essential.

Each APD reaching CERN from the manufacturer will be characterized and tested for signs of manufacturing defects or errors. This includes making measurements both upon receipt, and after irradiation with $\gamma$ rays from a $^{60}$Co source - a procedure which we have shown to provide an excellent predictor of how each device will perform (or fail) under the heavy neutron irradiation (over $10^{12}$ neutrons per cm$^2$) expected at CMS.

Some idea of how important this work is can be gleaned from figure 2 which shows the effects of $^{60}$Co gamma radiation on good and bad APD's.

These activities are carried out in a special APD laboratory at CERN [7] which is run by our group with the participation of the University of Minnesota and the Paul Scherrer Institute, and funded in part by the CMS project. More than a simple assembly line, it involves an ongoing research program which has already made many significant findings about APD's and their behaviour under CMS-like conditions.

A complete database will also be maintained with all device parameters, and it is continuously studied for any signs of changes in manufacturing. This database is also used in order to group APD's by their characteristics into sets which can be connected to a common power supply. These data will also be invaluable during CMS operation in order to understand the behaviour of the ECAL over time.

### 1.2.2 Endcap Muon Alignment

The CMS endcap muon alignment system is based on "NUCOPS", the NU CCD Optical Position System, which was developed at Northeastern University.

Our plans for the coming grant period, which overlaps with CMS construction, are to complete the work already begun on this project. This includes the completion of the calibration bench which will be used, finalization of the design and acquisition of the required hardware and software for the ISR2002 test. We will also complete production, calibration, and quality control of the approximately 300 NUCOPS subsystems which will be used in CMS.

### 1.2.3 Computing and Software

CMS represents an immense challenge to the online and offline computing and software systems. CMS collects $10^9$ events per year or 1 PetaByte ($10^{15}$ Bytes) of raw data per year. Despite the large sample, it is predicted that the hardware needs of CMS will be affordable, but nonetheless very challenging, due to the advancement of computing performance: Moore's law, which says that computing power per unit cost doubles every 18 months, roughly holds.

The software presents an even more significant challenge than the hardware. The high luminosity, centre-of-mass energy, and backgrounds render the LHC software environment considerably more complex than, for example, that of the Tevatron experiments.

Online, the level 2 and level 3 triggers (known as "HLT" or higher level triggers) are software based and must provide a rejection factor of 1000. Since 99.9% of events are rejected (for ever!) by the HLT, the software must meet very stringent quality criteria. Offline, the $10^9$ events recorded each year are calibrated, reconstructed and filtered in order to find the handful of events which indicate the most exciting physics discovery signals, such as the Higgs. Inadequate software quality or could render this "needle-in-the haystack" task impossible.

The collaborative environment is also a significant international challenge. The software must support scheduled and chaotic reconstruction and analysis of multi-PetaByte data sets by thousands of physicists, in about a hundred countries, over several decades. To meet these challenges CMS has initiated significant software and computing R&D programs. In addition, there is an ongoing program of work to support detector and trigger studies. There is a steady sequence of Technical Design Reports: DAQ TDR (December 2002), Core Computing and Software, or CCS, TDR (for December 2003), and Physics TDR (December 2004).

Northeastern will continue to play major leadership roles, in these activities. Taylor is Technical Coordinator for the International CMS Software and Computing Project [8] and Deputy Level 1 Project Manager for the US-CMS Software and Computing Project. Tuura, Deputy Architect of CMS software, will continue to ensure a coherent overall architecture, software frameworks, and services throughout the CMS application software domain. Osborne, the lead developer for CMS graphics and visualisation components will continue to develop the event display, interactive GEANT4 program, and other interactive applications. The specific plans for CMS software development are described below.

The CMS software model relies on a well-engineered base of software of frameworks, toolkits, and basic services to support physicists developing simulation, reconstruction, and analysis code. We plan to continue to contribute through our work on the CMS IGUANA (Interactive Graphics for User Analysis) project [3, 9–11], which is the sole responsibility of Northeastern. IGUANA has already delivered functional detector and event visualisation tools as described below.

We plan to facilitate the expansion and evolution of IGUANA by implementing an open analysis architecture [11]. IGUANA will present a coherent interface to physicists for a wide variety of analysis tasks. In order to meet their needs it will need to be an integral part of the experiments software: object oriented and ever more advanced data models, the GRID [12], and automated hierarchical storage management systems to name just a few. At the same time the analysis toolkits should be modular and non-invasive to be usable in different contexts within one experiment and generally across experiments.

The main architectural units foreseen for IGUANA, and for which early prototypes are just starting, are a thin *portability* and *utilities* layer and a small *kernel* that manages a number of *plug-in* modules. In addition there will need to be a number of interfaces to *external software*.

In addition to the core architecture and IGUANA activities, we expect to continue our contributions to software infrastructure as we have already done, for example: configuration management tools; package dependency analysers; and documentation systems.

### 1.2.4 Physics Studies

Taylor is now spending most of his time in US-CMS and CMS leadership roles. As the physics studies ramp up for the DAQ, Software/Computing, and Physics TDR the work of second postdoc will become increasingly important. The tasks will consist primarily of working with the PRS (Physics Reconstruction and Selection) groups to develop reconstruction and analysis algorithms for both the online software triggers and the offline filtering and analysis.

The main focus will be on ECAL-centric analysis studies, such as $H \to \gamma\gamma$. This facilitates the transfer knowledge of the detailed parameters of the ECAL readout, especially from our APD testing facility, to offline software algorithms in the simulation and reconstruction software. This will require close and continuous contact with the APD testing procedure both during the construction phase of CMS and throughout its running.

In particular, detailed simulations of ECAL response to both background and signal events should be started as soon as possible. The ECAL is a complex and sophisticated detector with many factors that contribute to its performance. These include the effects of cumulative radiation on noise, dark current, gain, and other key device parameters that are time-dependent and must be thoroughly understood in order to make best use of the data when it arrives.

Another key task to be performed is that of technical liaison, to ensure that the Core Computing and Software (CCS) deliverables from our IGUANA group are well integrated with PRS software and are well-matched to the physicists' needs. Such PRS–CCS inter-project tasks will include:

- working with our ("physics-innocent") graphics experts to ensure the event display and detector visualisation tools are tightly focused on PRS needs;
- deploying and integrating the new generic interactive tools (e.g. Lizard, Anaphe, perhaps ROOT, and so on) where previously ntuples and PAW were used;
- improving the productivity of physicists by adding IGUANA interfaces on existing tools to, for example, configure simulation or reconstruction jobs, create, copy, or filter event data sets, or to browse meta-data (e.g. run, event, MC parameters, calibration data, etc.);
- defining, implementing, and supporting useful TAGS (ntuple-like structures with pointers into the full event) for the four PRS groups as they require, and in a coherent fashion;
- development of training materials for newcomers to the PRS and CCS software, and participation giving interactive tutorials.

## 1.3 Pierre Auger Observatory

**Personnel** – Faculty: S. Reucroft, J. Swain; Postdoctoral: T. Paul, L. Taylor; Graduate Students: J. Gonzalez, T. McCauley

The Pierre Auger Observatory (PAO) [13], currently under construction in Mendoza, Argentina, has as its aim the investigation of the highest energy cosmic rays. Numerous events have now been reported by experiments with much smaller apertures of extensive air showers produced by primaries with energies well in excess of $10^{20}$ eV. There is, however, very little understanding of what mechanisms could give rise to such macroscopic energies (several Joules – or the kinetic energy of a fast-flying tennis ball) for single subatomic particles. Adding further to the puzzle, protons or nuclei with these energies interact strongly with the cosmic microwave background which is so blue-shifted that it causes photodisintegration. This leads to the celebrated Greisen-Zatsepin-Kuz'min (GZK) cutoff [1] which requires sources of such particles to be relatively close in order to reach us at all.

PAO is ideally suited to detailed studies of such events, being a hybrid detector which can detect both atmospheric fluorescence produced by extensive air showers, and particles which reach the ground. In addition, it has the added advantage that the Southern Hemisphere site is the already under construction and almost nothing is known so far about the southern sky as seen in UHECR's.

Our group has built up a significant publication record in cosmic ray astrophysics in the last grant period [14–42] and have been formally accepted into the PAO collaboration where we have made significant contributions building on our experience in accelerator-based physics. Our involvement in this project is particularly natural for many reasons, and fits very well in the gap between the final L3 results and the start of CMS data-taking. In this proposal we are requesting minimal base funding for the PAO work of our group (see Budget Justification), with most of our project involvement described in a separate proposal to the NSF.

We look forward to a rich exchange of tools and techniques between traditional accelerator-based physics and this exciting new domain. In particular, we plan to be heavily involved in deployment and commissioning of the full surface array over the next few years, but expect our strongest contributions will be to tasks consistent with our existing expertise, particularly in software, and thus maximize opportunities to apply our experience in accelerator-based HEP. In particular, we propose to contribute on four fronts: framework design and implementation for the simulation and reconstruction software; data storage and access; detailed detector simulation; and reconstruc-

[1] Greisen, K., Phys. Rev. Lett. 16 (1966) 788, Zatsepin, G. T. and Kuzmin, V. A., JETP Lett. 4 (1966) 78

tion and analysis algorithms.

We outline each of these in the following sections:

### 1.3.1 Software Framework

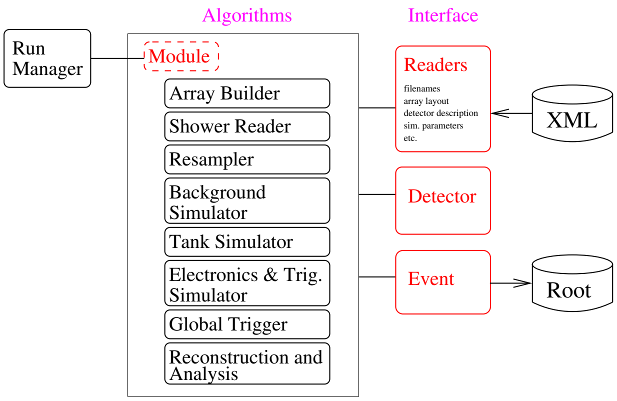


Figure 3: Algorithm modules involved in simulation and reconstruction of PAO data. Algorithms will be registered with a run manager, following a so-called factory design pattern.

As PAO will take data for several decades, involve hundreds of collaborators including several generations of students, it is crucial that the core software be well-designed, maintainable and modular. In the case of PAO, the requirement for careful design is especially acute given that there is no central laboratory where most of the active collaborators spend their time.

For purposes of design studies and engineering array work, a number of codes, many of which are C++ translations of older `FORTRAN` programs, have been prepared and chained together. This approach is sufficient for the early development phases, but would pose maintainability difficulties over the 20 year lifetime of the experiment. We feel that the design and development of large, robust software packages is one or our strong suits as we have carried out similar tasks for the L3, DØ and CMS experiments.

We have begun devising design strategies together with collaborators at UCLA, UNAM, and elsewhere which will allow for a robust framework into which existing algorithms can be incorporated. Some of these ideas have been presented to the Data Processing and Analysis (DPA) subtask within the collaboration and were favourably received. A simple prototype framework has been prepared to assist in developing ideas.

Figure 3 indicates schematically the different algorithms involved in proceeding from simulated air showers up to final data analysis. The prototype framework follows a so-called factory design pattern, in which all the algorithms, or "modules" are registered with a central factory, called "Run Manager" in the figure. This scheme allows developers to work independently on different algorithms, or on different approaches to implementing the same algorithm. Inserting one's algorithm into the framework only requires registering it with the Run Manager. One can use the same framework to carry out full-blown simulation, simulation of calibration runs, specific tests of individual modules, or reconstruction and analysis of real data; the different cases are handled by different control files.

### 1.3.2 Detailed Detector Simulation

Initial design studies for Auger were based on dedicated simulation packages. We propose to provide a simulation based on the GEANT4 toolkit, a package which is the *de-facto* standard of the HEP community for simulating the behaviour of detectors. The rationale behind this proposal is threefold. Firstly, the extensive arsenal of tools provided by GEANT4 will allow the detail of the simulation to grow as needs are identified. Secondly, one can be justifiably optimistic about the longevity and evolution of this package. Thirdly, we can leverage our group's experience on CMS where they have implemented a generic interactive GEANT4 visualisation and debugging tool. We have already prepared a prototype simulation of the surface detectors (see Figure 4) using this package.

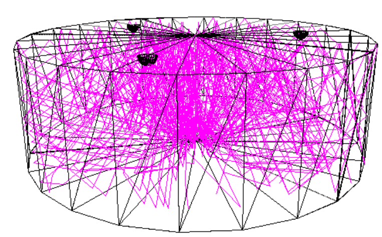

Figure 4: Prototype simulation of a surface detector using GEANT4. The cylindrical tank and three hemispherical photomultipliers are visible. A muon is incident from above and produces Cerenkov photons, which can be seen bouncing off the reflective tank walls.

We plan to work in close collaboration with our PAO colleagues who are currently studying the details of detector response to tune the simulation accordingly. The GEANT4 simulation prototype will be fully incorporated into the prototype framework discussed in the previous section.

#### 1.3.3 Data Storage and Access

The interface portion of the framework will be charged with storing and retrieving the various different sorts of objects of interest. This issue of persistency is not straightforward, and though interim solutions are being adopted, we propose to explore longer term strategies.

We are planning to develop a set of interfaces and tools for reading, writing, and exchanging data using C++ and XML (eXtensible Markup Language) format, which are easily usable by non-experts. Prototypes have already been adopted by the Auger collaboration and are being employed in the photomultiplier tube electronics simulation and database. We also use these tools for detector descriptions in our GEANT4 simulation and for general steering and control in the prototype framework. More widespread usage in the collaboration appears likely, and we plan to develop complimentary XML tools for display and database manipulation. Paul has been asked to coordinate general software libraries for the experiment, which includes our XML tools.

For potentially more complex persistency issues, such as storage of the PAO data sample, we have an excellent opportunity to leverage our CMS and D∅ software expertise.

#### 1.3.4 Reconstruction and Analysis

Once the framework is finalized, we plan to develop reconstruction algorithms. As a group, we have extensive experience in the rather difficult and ill-posed inverse problem of the reconstruction of underlying physics from incomplete and imprecisely measured information. We would like to follow up on some phenomenology, which we have already investigated, including the idea that UHECR's could be due to exotic primaries such as magnetic monopoles [37] or heavy nuclei [18,23,24,31] and extensions of the Standard Model in which interactions are different due to large extra dimensions [25–27]. We are also very interested in pursuing studies of hadronic interaction models which, in terms of center-of-mass energy, are essentially the same ones which we will produce at the LHC. The idea of making connections here between the two experiments is a particularly interesting one which we plan to pursue actively.

### 1.4 OTHER ACTIVITIES

As a group we will continue our diverse and significant efforts in outreach and education (which are summarized in section 2.4). While for most of these activities we are not seeking funding in this proposal, we do request modest funding in order to involve more high school students in our research over the summers.

# 2 Prior NSF Support Results

Our central goals over the last grant period were to exploit the excellent data from L3 and DØ to perform precise tests of the Standard Model and to search for new physics. This program has been spectacularly successful, including first and best measurements of numerous parameters, determination of the pole mass of the $Z^0$ so well that it is now taken as a fundamental measured parameter, discovery of the top quark, measurement of the $W$ mass and the electroweak mixing angle, and an enormous variety of other results which confirm the basic correctness of the Standard Model as a description of physics up to several hundred GeV. Concurrently we have made major contributions to the CMS experiment for the LHC, which is the next most powerful accelerator to become available, and will afford us an even deeper understanding of the universe at its most fundamental level.

## 2.1 THE L3 EXPERIMENT

**Personnel** – Faculty: S. Reucroft, J. Swain; Postdoctoral: T. Paul, L. Taylor; Graduate Students: S. Palit (graduated 1998), S. Villa (graduated 1999).

The basic aim of LEP was to make detailed studies of the electroweak sector of the Standard Model by producing $Z$ and $W$ bosons. This entailed fundamental measurements such as the $Z$ lineshape, the masses of the $Z$ and $W$ bosons, and the weak mixing angle, and has been an enormous success [1]. We contributed to many of the measurements which go into the extraction of these fundamental quantities, as well as making several measurements to push beyond the boundaries of the Standard Model and search for new physics.

The puzzle of generations – of why nature chose to make three copies of the universe to start off with, and then let two of them rapidly decay away leaving us with what we see in daily life is one on which essentially no light is shed by the Standard Model, so many of our efforts to go beyond it were done with fermions of the third generation ($b$'s, $t$'s and $\tau$'s).

Among our accomplishments in $\tau$ physics are:

- the measurement for the first time [43–45] of the anomalous magnetic and electric dipole moments of the tau, where not only are our numbers the only ones accepted by the Particle Data Group [46], but we also developed all of the accompanying theory and analysis techniques [47,48]. This measurement is the direct analog of the famous $g-2$ measurements, which had previously only been made for electrons and muons;

- limits on the charged current analogs of these quantities where a $W^\pm$ boson replaces a photon [49, 50];

- studies of the couplings of the tau to the $Z^0$ and the $W$ measured via tau polarisation [51] and the development of techniques to disentangle this from possible deviations from a pure $V-A$ structure in the charged current;

- new techniques for setting limits on the tau neutrino mass and possible mixings [52–54];

We also extensively investigated the physics of the $b$-quark, including work on B lifetimes [55], rare B decays, searches for lepton-flavour violating and flavour-changing neutral currents in B decays, and measurements of $\Upsilon$ production (mainly done during the next to last grant period).

The combined LEP results make an impressive case for the correctness of the Standard Model, and can be used to place stringent limits on possible deviations from the basic structure of the theory. To take advantage of this, we developed a technique to use the full electroweak data to make the first determination of the CKM matrix element $|V_{tb}|$ without invoking assumptions about unitarity, and, rather remarkably, without even needing on-shell $t$-quarks or $W$ bosons [56, 57].

We also studied $W^\pm$ bosons directly [58], playing a major role in the search for anomalous triple gauge boson couplings. In particular, Villa led the L3 effort in fitting for the anomalous couplings, and this work was included in his thesis [59] as well as in the published results [60]. We also investigated decays of the $W^\pm$ and $Z^0$ into two or three pions [61].

## 2.2 THE DØ EXPERIMENT

**Personnel** – Faculty: G. Alverson, S. Reucroft, D. Wood; Postdoctoral: T. Yasuda (until Nov. 1999), P. Hanlet (until Dec. 1999), N. Parashar, D. Shpakov (since Aug. 2000); Graduate Students: S. Doulas; Undergraduate Students: F. Poulin, M. Marcus, N. Hodson, N. Kirsch, R. Leiter, J. Vaughn, A. Odom, B. Wiggins; Visiting scientist: I. Churin.

### 2.2.1 Physics analysis of Tevatron Run 1

The group was primarily involved in electroweak physics and top physics in Run 1 [2]. In this period, DØ produced the world's most precise measurements [62, 63] of the trilinear couplings $WW\gamma$, $WWZ$, $ZZ\gamma$ by studying final states containing $W+\gamma$, $W+W$, $W+Z$, and $Z+\gamma$. In all, fourteen DØ papers on trilinear gauge couplings were published.

Wood served as the DØ physics coordinator in the period 1998-1999, with responsibility for review and coordination of all DØ physics output. This turned out to be one of the most fruitful periods for physics analysis with about 20 publications per year. He also oversaw the initial transition from Run 1 physics groups to a new group oriented to the new challenges and opportunities of physics at Run 2.

Parashar has completed a preliminary analysis of the width of the $W$ [64], using the shape of the transverse momentum spectrum to extract a value which is independent of most assumptions about physics beyond the Standard Model. In particular, unlike the $W$ width derived from the ratio of $W$ to $Z$ cross sections times leptonic branching ratio, this analysis does not require assumptions about the SM couplings of the $W$ boson to quarks and leptons.

### 2.2.2 Hardware Activities

The Northeastern group designed, built (along with FNAL), and installed a system of LED + fiber optic calibration pulsers for the 6000-channel muon scintillation system [65]. The experiment relies on the muon scintillator to provide a first level trigger on muons, to tag muon hits in the drift tubes with the correct bunch crossing, and to measure the time of flight of charged particles which reach the muon chambers. The calibration system was essential in the testing of all of the phototubes, adjusting the timing trim cables of the counters, commissioning the muon trigger, and monitoring phototube aging.

The LED's produce light which is matched to the output of the wavelength shifting fibers. The timing and amplitude of the light pulses are controlled by VME modules, and the amplitude is monitored by a system of PIN diodes. The pulses can be tuned to mimic the time and amplitude of actual muons, or can be scanned to test the turn-on thresholds and to map out the timing gates. The calibration system monitors the gains of the phototubes as they age so that the high voltage and/or thresholds can be adjusted to keep the timing edge in the same place. The stability of the calibration system itself, which has been excellent, is essential for reliable tracking of the PMT gains. The system, completed and commissioned under the direction of Doulas, has proven to be one of the most useful tools in understanding the muon scintillator system.

### 2.2.3 Software Activities

Northeastern played a large role in the development of online software for reading out, controlling, and calibrating the muon system electronics. Northeastern shares the responsibility for muon data acquisition with FNAL, and is responsible for online calibration and down-loading. Wood is the muon DAQ software coordinator.

We developed DSP readout code and tools for downloading calibration constants from the host to the front ends where they are applied [66]. This provides corrected times and drift distances to the Level 2 and Level 3 trigger systems, eliminating the need for database access during reconstruction. Level 3 data are transferred over fast serial links to muon readout crates in the counting house. These crates contain embedded processors which control the readout and assembly of the data for the Level 3 trigger system. The associated code includes synchronization checking, error reporting, and a graphical user interface which allows shift-takers to control and monitor the readout crates and the front ends.

We have developed a DØ-specific 3D visualization program, DØ scan, based on the IGUANA [3] toolkit from CMS. In addition to providing a valuable opportunity to check IGUANA in an application outside the CMS environment, DØScan has also been used to extensively debug DØ software using Monte Carlo data. With actual data becoming available, we expect it will also be a valuable tool for debugging the detector, as well as providing valuable insight for algorithm development and physics insight.

## 2.3 THE CMS EXPERIMENT

**Personnel** – Faculty: S. Reucroft, G. Alverson, J. Swain, E. von Goeler; Postdoctoral: T. Paul, L. Taylor; Undergraduate Students: R. Leiter, S. Nicol, A. Odom, E. Salazar, B. Wiggens; Technical: J. Macleod, J. Moromisato, Y. Musienko, R. Terry.

Northeastern played a major role in the US in getting NSF groups involved in CMS, and holds the umbrella grant under which all NSF-funded CMS activities are performed. Our particular involvement has been in the ECAL readout, the endcap muon alignment system, and in software and computing.

### 2.3.1 Electromagnetic Calorimeter

The decision to use avalanche photodiodes (APD's) was essentially forced on CMS by the requirement of a photodetector with intrinsic gain which would be able to perform in a high magnetic field, as demonstrated by our group [4]. The major challenge then became to develop an APD which could also withstand the intense neutron irradiation (over $10^{12}$ neutrons per square centimetre over the lifetime of the experiment) to which they would be subjected. This launched a multi-year program of R&D with several collaborating institutions, including the manufacturers Hamamatsu and EG&G.

Avalanche photodiodes, although they are two-terminal devices, are remarkably complex with a panoply of parameters which must be carefully measured and understood, and which can change in response to a wide variety of factors, including irradiation. They include quantum efficiency, gain, capacitance, noise, excess noise factor and dark current as functions of voltage and temperature, sensitivity to the "nuclear counter effect" where a charged particle deposits energy in the device by ionization and fakes photons, *etc.*

Radiation hardness has proven to be a remarkably elusive characteristic. Damage can arise due to gamma rays or neutrons, and due to different mechanisms. For example, gamma rays can blacked silicon dioxide windows, mandating the use of silicon nitride, while neutrons can even change the effective doping of silicon by transmutation of silicon. After many investigations [5, 6, 67–73] including detailed device modelling [74], we finally arrived at a design which is suitable. At present we are continuing to test APD's at CERN in a special lab dedicated to that purpose [7] as described in section 1.2.1. We are also following the behaviour of the devices in beam tests [75].

### 2.3.2 Endcap Muon Alignment System

The COPS system [68, 76] is an optical beam sensing device that can measure transverse displacements with accuracy of a few microns. An analog readout prototype with a set of four linear CCD arrays arranged around a square aperture, and illuminated by a cross-hair laser, was built and tested. Performance test results demonstrate a linearity better than 5$\mu$m throughout an active transverse range of over 20mm. The reproducibility of the measurements was better than 2$\mu$m, with a long-term stability of 5$\mu$m.

A calibration procedure for COPS, as well as a bi-directional version, was developed and used in the ISR2000 integrated test at CERN. Based on our analysis of that data, the Barrel Muon group have requested the inclusion of a number of COPS devices in their system. Finally, we developed the "NUCOPS", a box like configuration of the bi-directional COPS, with improved shading, and adjustable openings.

In 2000, COPS was officially declared the baseline sensor for the EMU alignment. We believe that our work was instrumental in that decision. We have built a test setup for NUCOPS at Northeastern University, and are currently producing the required NUCOPS for our tests, as well as for a parallel test being carried out at Fermilab.

### 2.3.3 Software and Computing

Northeastern first became active in CMS software in the mid to late 1990's. We made a number of significant early contributions, including:

- CMS Fortran standards and automated code checking tools;
- CMKIN, the physics generator interface and persistency mechanism;
- CMDB, a thin file-system interface layer for logical handling of meta-data and event I/O;
- CMSCAN, an interactive 3D event and detector visualisation system [77].

These tools have been in widespread use for a number of years. We then played an active role in the successful CMS transition to an Object-Oriented software system.

During the last three years, Taylor initiated and led the highly successful US-CMS "Core Applications Software" activities [78–80]. These are now part of the formal "US-CMS Software and Computing Project" for which Taylor is Deputy Level 1 Project Manager. He is also Technical Coordinator for the international CMS Software and Computing Project, with responsibility for the overall CMS Software and Computing planning [8].

In the wider HEP context, we are also playing major roles. Taylor participated in the ICFA Networking Task force to evaluate future HEP networking requirements and technologies [81, 82]. He evaluated the use of satellite television broadcasting for global data transfer and communications [83]. We are active in the HEPVis HEP-wide visualisation project [84–86] and in May 2001 we organised and ran the very fruitful "Fifth HEPVis workshop" at Northeastern in Boston [87]. More recently, Taylor convened and summarised the "Data Analysis and Visualisation" track [88] at the Computing in High Energy Physics (CHEP) conference in Beijing.

In addition to these managerial responsibilities, the group is actively developing key components of software, with the main responsibility being the provision and/or integration of the tools for the User Analysis Environment. Two software engineers (Tuura and Osborne), who are not funded in the context of this proposal, are working in our CMS software group which has achieved a number of significant successes as described below.

**IGUANA: Interactive Graphics for User Analysis**

The focus of the group in the last few years has been to provide generic tools for interactive data analysis. We have created a fully Object-Oriented toolkit, known as IGUANA [3, 9–11]. The (very successful) IGUANA strategy has been to use freely available software (e.g. Qt, SoQt, OpenInventor, OpenGL, HEPVis) and package and extend it to provide a general-purpose and experiment-independent toolkit. IGUANA is an Object-Oriented and modular C++ toolkit covering graphical user interfaces, high performance 2-D and 3-D graphics, and generic data and scene browsers.

We have deployed IGUANA with the CMS GEANT4 package (OSCAR) and the CMS reconstruction software (ORCA [89]), as well as on DØ , L3, and PAO experiments. IGUANA has already proven its value by detecting a number of errors in the simulation and reconstruction code. Figure 5 shows a screen shot from IGUANA showing its use for CMS and DØ event display, as well as GEANT4 visualisation (of CMS).

**Software Development and Quality Tools**

The IGUANA team has maintained the coherence of the configuration for all external software packages used by CMS (about 50) [90]. In addition, a positive side-effect of our IGUANA developments is our development of a number of software tools which enhance the quality of the software and the overall development environment. While these are not primary missions of our group, we ensure that useful tools are packaged, deployed, and supported throughout CMS and even beyond - in particular for DØ and PAO.

We developed a software package dependency and metric analyser known as Ignominy [91], which determines the causes of couplings between software packages. This enables developers to reduce or eliminate undesirable couplings which could otherwise lead to an unmaintainable monolithic software system. Ignominy also quantifies code quality using well-accepted software metrics such that remedial action can be prioritised. Ignominy has also been used to analyse ATLAS software, the Lizard and ROOT analysis tools, the CERN Anaphe libraries (CERNLIB replacement) and the GEANT4 detector simulation toolkit.

We also developed a set of XML/XSL-based tools to ensure a consistent, complete, and flexible documentation system, covering a wide range of richly and consistently inter-linked documents describing: use-cases, scenarios and constraints, requirements, architectural design documents and plans, code reference manuals, user guides and tutorials [92].

## 2.4 OTHER ACTIVITIES

We have made many contributions to the physics of ultra-high energy cosmic rays as part of our buildup towards joining the PAO experiment. These have included works on the photo-disintegration of nuclei, explanations of puzzling features of the cosmic ray spectrum including events above the GZK cutoff, and the possibility that ultra-high energy cosmic rays might be exotica such as heavy nuclei or magnetic monopoles. We have also worked on transferring tools and technologies from traditional laboratory-based HEP to this new domain.

We are also developing, as an outgrowth of both the CMS APD work and the PAO, a novel approach to the detection of extensive air showers over very large areas using scintillating tiles equipped with APD readouts and a GPS based timing system. Chris-

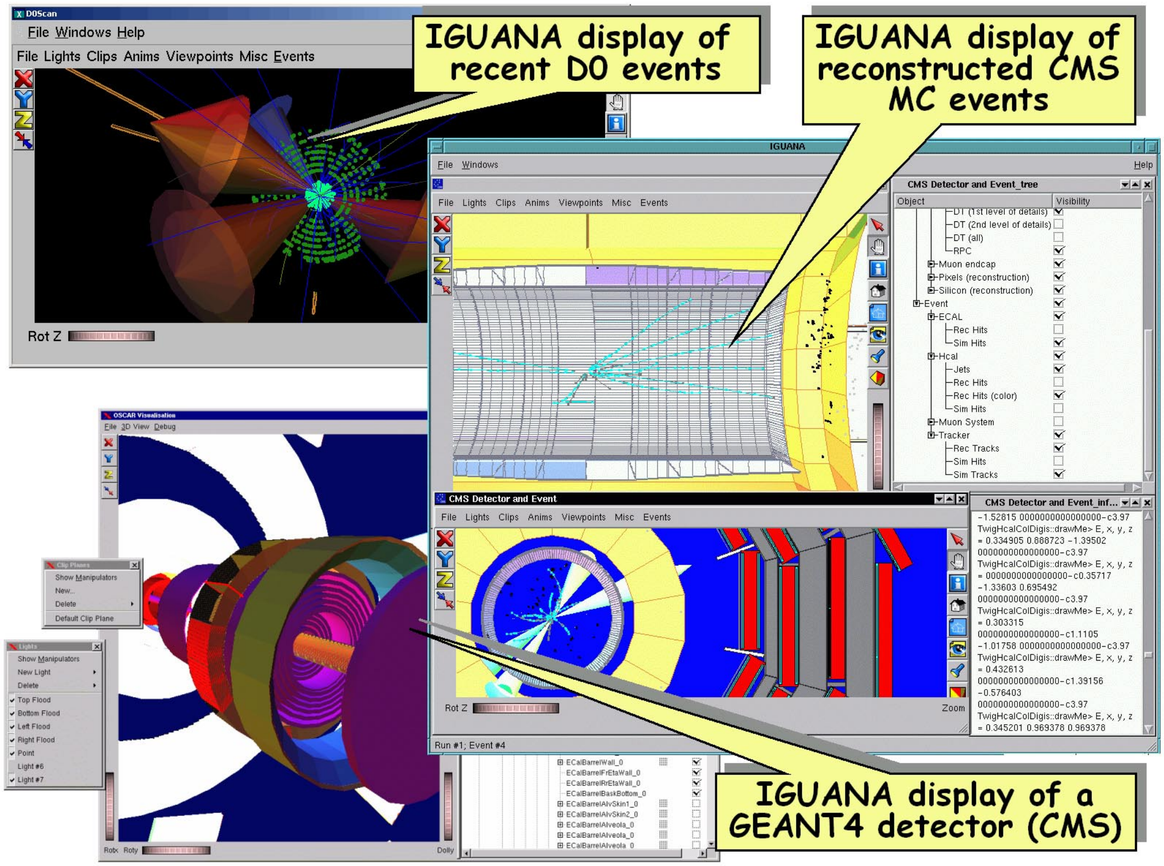


Figure 5: Screen shot showing CMS and D0 event displays and interactive GEANT4 applications developed by the group using our generic IGUANA toolkit.

tened “SCROD”, for *School Cosmic Ray Outreach Detector* [14] we hope it will bring the excitement of particle physics to very young students. Other activities include filing for patents on optical [93] and medical devices [94], and the development of new statistical techniques [95].

We have made major commitments to outreach and education. Two of our projects, which are NSF-funded, are the Research Experience for Undergraduates (REU) program [96] at CERN which sends US students to the CERN summer student program, and the related RET program for teachers [97]. In addition, we have maintained a steady level of undergraduate involvement in our research with 2–3 students working with us at any given time. In the summers we usually take an additional 3 high school students and have them work with us. We contributed to the NSF/DoE-funded Quarknet project [98] and co-organized an intensive three-week QuarkNet workshop for 17 Boston-area high school teachers in Summer 2000, and continue to work with them on introducing particle physics in the classroom.

On a wider scale, Reucroft and Swain write two weekly columns [99, 100], one syndicated and one appearing in the Boston Globe and several other papers, and are frequent radio guests. They have contributed to a number of popular science magazines, including Scientific American’s “Ask the Expert” [101], and New Scientist’s “Last Word” [102]. In addition, Swain appears regularly on the Discovery Channel in Canada, and on Discovery Science in the US, explaining physics to the general public, and even wrote, in Spanish, a front-page article for the Argentine magazine “Ciencia Hoy” (Science Today) [103]. We were involved in an artistic project using event display images for the German National Millennium Exhibition in Bonn [104].

# References cited


[1] The L3 Collaboration published more than 100 physics papers since 1998. For details, see: `l3www.cern.ch/paper/publications.html` or: `www.slac.stanford.edu/spires/hep/`.

[2] The D0 Collaboration published about 50 physics papers since 1998. For details, see: `www-d0.fnal.gov/public/d0_physics_v2.html` or: `www.slac.stanford.edu/spires/hep/`.

[3] G. Alverson, I. Osborne, L. Taylor, L. Tuura, IGUANA: Interactive Graphical User Analysis, `http://iguana.cern.ch`.

[4] J. Marler et al., Studies of avalanche photodiode performance in a high magnetic field, Nucl. Instrum. Meth. **A449**, 311–313 (2000).

[5] Y. Musienko, S. Reucroft, D. Ruuska, and J. Swain, Studies of neutron irradiation of avalanche photodiodes using Cf-252, Nucl. Instrum. Meth. **A447**, 437–458 (2000).

[6] K. Deiters et al., Properties of the avalanche photodiodes for the CMS electromagnetic calorimeter, Nucl. Instrum. Meth. **A453**, 223–226 (2000).

[7] K. Deiters et al., CMS ECAL APD quality assurance facility, Proceedings of the 6th Workshop on Electronic for LHC Experiments, Cracow, Poland, 11-15 Sep 2000.

[8] L.Taylor, The CMS Software and Computing Project: Organisation, Tasks, Schedule, and Resources, CMS IN/1999-032.

[9] G. Alverson, I. Gaponenko and L. Taylor, IGUANA – Interactive Graphical User Analsysis, CMS IN/1999-042.

[10] G. Alverson, I. Osborne, L. Taylor, L. Tuura, The IGUANA Interactive Graphics Toolkit with Examples from CMS and DØ, in *Proceedings of CHEP 2001*, edited by H. Chen, Beijing, P.R. China, 3-7 September 2001.

[11] G. Alverson, I. Osborne, L. Taylor, L. Tuura, Coherent and Non-Invasive Open Analysis Architecture and Framework with Applications in CMS, in *Proceedings of CHEP 2001*, edited by H. Chen, Beijing, P.R. China, 3-7 September 2001.

[12] L. Taylor, with K. Holtman et al., CMS Requirements for the Grid, in *Proceedings of CHEP 2001*, edited by H. Chen, Beijing, P.R. China, 3-7 September 2001.

[13] `http://www.auger.org/`.

[14] L. A. Anchordoqui et al., School cosmic ray outreach detector (SCROD), (2001), hep-ex/0106002. See also `http://www.hep.physics.edu /scrod`.

[15] L. A. Anchordoqui, M. T. Dova, L. N. Epele, and J. D. Swain, Effect of the 3-K background radiation on ultrahigh energy cosmic rays, Phys. Rev. **D55**, 7356–7360 (1997).

[16] L. A. Anchordoqui, M. T. Dova, L. N. Epele, and J. D. Swain, Opacity of the microwave background radiation to ultrahigh- energy cosmic rays, Nucl. Phys. (Proc. Suppl. ) **52B**, 249–252 (1997).

[17] L. A. Anchordoqui, M. T. Dova, L. N. Epele, and J. D. Swain, A depression before the bump in the highest energy cosmic ray spectrum, Phys. Rev. **D57**, 7103–7107 (1998).

[18] L. A. Anchordoqui, T. P. McCauley, S. Reucroft, J. D. Swain, and M. T. Dova, Possible explanation for the tail of the cosmic ray spectrum, Phys. Lett. **B482**, 343–348 (2000).

[19] L. A. Anchordoqui et al., Fractal electromagnetic showers, Nucl. Phys. Proc. Suppl. **97**, 199–202 (2001).

[20] L. A. Anchordoqui et al., Air shower simulation using GEANT4 and commodity parallel computing, (2000).

[21] L. A. Anchordoqui et al., Simulation of water Cerenkov detectors using GEANT4, Nucl. Phys. Proc. Suppl. **97**, 196–198 (2001).

[22] G. Alverson et al., Using TOP-C for Commodity Parallel Computing in Cosmic Ray Physics Simulations, Nucl. Phys. Proc. Suppl. **97**, 193–195 (2001).

[23] L. A. Anchordoqui et al., A pot of gold at the end of the cosmic 'raynbow'?, Nucl. Phys. Proc. Suppl. **97**, 203–206 (2001).

[24] L. A. Anchordoqui, M. Kirasirova, T. P. McCauley, S. Reucroft, and J. D. Swain, On the nature of cosmic rays above the Greisen-Zatsepin- Kuz'min cutoff, Phys. Lett. **B492**, 237–244 (2000).

[25] L. A. Anchordoqui, T. P. McCauley, S. Reucroft, and J. Swain, Echoes of the fifth dimension?, Phys. Rev. **D63**, 027303 (2001).

[26] L. Anchordoqui et al., Extensive air showers with TeV-scale quantum gravity, Phys. Rev. **D63**, 124009 (2001).

[27] L. Anchordoqui et al., Hadronic interactions, precocious unification, and cosmic ray showers at Auger energies, Mod. Phys. Lett. **A16**, 809–820 (2001).

[28] L. A. Anchordoqui et al., The mysterious ultrahigh energy cosmic ray clustering, 2001.

[29] L. Anchordoqui, H. Goldberg, S. Reucroft, and J. Swain, Extragalactic sources for ultra high energy cosmic ray nuclei, 2001.

[30] G. E. Romero, S. Perez-Bergliaffa, L. A. Anchordoqui, and J. A. Combi, Ultrahigh-energy cosmic rays from Cen A, Grav. Cosmol. **S5**, 188–191 (1999).

[31] L. A. Anchordoqui, G. E. Romero, and J. A. Combi, Heavy nuclei at the end of the cosmic ray spectrum?, Phys. Rev. **D60**, 103001 (1999).

[32] L. A. Anchordoqui, M. T. Dova, and S. J. Sciutto, Extensive air showers rounded up by AIRES + SIBYLL/QGSJET, in *Proceedings of the 26th International Cosmic Ray Conference (ICRC 99)*, Salt Lake City, Utah, 17–25 August 1999.

[33] L. A. Anchordoqui, Cosmic dust grains strike again, Phys. Rev. **D61**, 087302 (2000).

[34] G. Sigl, D. F. Torres, L. A. Anchordoqui, and G. E. Romero, Testing the correlation of ultra-high energy cosmic rays with high redshift sources, Phys. Rev. **D63**, 081302 (2001).

[35] L. A. Anchordoqui and D. F. Torres, Non-extensivity effects and the highest energy cosmic ray affair, Phys. Lett. **A283**, 319–322 (2001).

[36] M. T. Dova et al., Monte Carlo modelling of radio emission from extensive air showers, Prepared for 26th International Cosmic Ray Conference (ICRC 99), Salt Lake City, Utah, 17-25 Aug 1999.

[37] M. T. Dova and J. Swain, Modelling high energy monopole induced air showers, Prepared for 26th International Cosmic Ray Conference (ICRC 99), Salt Lake City, Utah, 17-25 Aug 1999.

[38] M. T. Dova, L. N. Epele, H. Fanchiotti, C. A. Garcia-Canal, S. J. Sciutto, J. Swain, and L. Taylor, Monte Carlo Calculation of Radio Emission from Extensive Air Showers, in *Proceedings of the 25th International Cosmic Ray Conference*, edited by M. S. Potgieter, B. C. Raubenheimer, and D. J. van der Walt, volume 7, Durban, South Africa, 30 July – 6 August 1997, Space Research Unit.

[39] J. Swain and L. Taylor, Software Tools in High Energy Physics, in *Proceedings of the 25th International Cosmic Ray Conference*, edited by M. S. Potgieter, B. C. Raubenheimer, and D. J. van der Walt, volume 7, Durban, South Africa, 30 July – 6 August 1997, Space Research Unit.

[40] J. Swain and L. Taylor, Computing Trends in High Energy Physics, in *Proceedings of the 25th International Cosmic Ray Conference*, edited by M. S. Potgieter, B. C. Raubenheimer, and D. J. van der Walt, volume 7, Durban, South Africa, 30 July – 6 August 1997, Space Research Unit.

[41] J. Swain and L. Taylor, Particle Interaction Modelling in High Energy Physics, in *Proceedings of the 25th International Cosmic Ray Conference*, edited by M. S. Potgieter, B. C. Raubenheimer, and D. J. van der Walt, volume 7, Durban, South Africa, 30 July – 6 August 1997, Space Research Unit.

[42] L. A. Anchordoqui, M. T. Dova, and L. N. Epele,, Photonuclear Interactions of Extremely High Energy Cosmic Rays, in *Proceedings of the 25th International Cosmic Ray Conference*, edited by M. S. Potgieter, B. C. Raubenheimer, and D. J. van der Walt, volume 7, Durban, South Africa, 30 July – 6 August 1997, Space Research Unit.

[43] L3 Collab., M. Acciarri *et al.*, Measurement of the anomalous magnetic and electric dipole moments of the tau lepton, Phys. Lett. **B434**, 169 (1998).

[44] L. Taylor, Anomalous magnetic and electric dipole moments of the tau, in *Proceedings of the TAU 98 Workshop*, edited by A. Pich and A. Ruiz, Santander, Spain, 14-17 September 1998, to appear in: Nucl. Phys. B (Proc. Suppl.), **hep-ph/9810463**.

[45] J. Swain and L. Taylor, Anomalous Electromagnetic Moments of the Tau Lepton, in *Proceedings of the PASCOS 98 Conference*, edited by P. Nath, Northeastern University, Boston, 22-28 March 1998.

[46] Groom, D.E. and others, Review of Particle Physics, The European Physical Journal **C15**, 1+ (2000).

[47] S. S. Gau, T. Paul, J. Swain, and L. Taylor, Radiative tau lepton pair production as a probe of anomalous electromagnetic couplings of the tau, Nucl. Phys. **B 523**, 439 (1998).

[48] T. Paul, J. Swain and Z. Wąs, Library of anomalous $\tau\tau\gamma$ couplings for $\tau^+\tau^-(N\gamma)$ Monte Carlo programs, Comput. Phys. Commun. **124**, 243 (2000).

[49] M.T. Dova, J. Swain and L. Taylor, Anomalous charged current couplings of the tau and implications for tau compositeness and two-Higgs doublet models, Phys. Rev. **D 58**, 015005 (1998).

[50] M.T. Dova, J. Swain and L. Taylor, Constraints on anomalous charged current couplings, tau neutrino mass and fourth generation mixing from tau leptonic branching fractions, in *Proceedings of the TAU 98 Workshop*, edited by A. Pich and A. Ruiz, Santander, Spain, 14-17 September 1998, to appear in: Nucl. Phys. B (Proc. Suppl.), **hep-ph/9811209**.

[51] M. Acciarri et al., Measurement of the Michel parameters and the average tau- neutrino helicity from tau decays at LEP, Phys. Lett. **B438**, 405–416 (1998).

[52] J. Swain and L. Taylor, Phys. Rev. **D 55**, 1 R (1997).

[53] M.T. Dova, J. Swain and L. Taylor, Sensitivities of one-prong tau branching fractions to tau neutrino mass, mixing, and anomalous charged current couplings, in *Invited talk at the Tau-Charm Workshop*, SLAC, Stanford, USA, 6-9 March 1999, (unpublished), **hep-ph/9903430**.

[54] S. Palit, An Upper Limit for the Tau Neutrino Mass, (1998), Ph.D. thesis, Northeastern University, Boston, Massachussetts, USA.

[55] M. Acciarri et al., Measurement of the average lifetime of b-hadrons in Z decays, Phys. Lett. **B416**, 220–232 (1998).

[56] J. Swain and L. Taylor, First Determination of the Quark Mixing Matrix Element $V_{tb}$ Independent of Assumptions of Unitarity, Phys. Rev. **D58**, 093006 (1998).

[57] J. Swain and L. Taylor, First determination of the quark mixing matrix element $V_{tb}$ from electroweak corrections to Z decays and implications for CKM matrix unitarity, in *Proceedings of the PASCOS 98 Conference*, edited by P. Nath, Northeastern University, Boston, 22-28 March 1998.

[58] L. Taylor, in *Proceedings of the XVIIth International Conference on Physics in Collision*, edited by H. Heath, Singapore, 1998, World Scientific, **hep-ex/9712016**.

[59] S. Villa, Measurements of the Triple Gauge Couplings of the W Boson at LEP2, (June 2000), Ph.D. thesis, Northeastern University, Boston, Massachussetts, USA.

[60] M. Acciarri et al., Measurement of triple-gauge-boson couplings of the W boson at LEP, Phys. Lett. **B467**, 171–184 (1999).

[61] T. Paul et al., Branching ratios of the $Z^0$ and $W^\pm$ into 2 and 3 pions, Phys. Lett. **B439**, 437–440 (1998).

[62] B. Abbott et al., Studies of W W and W Z production and limits on anomalous W W gamma and W W Z couplings, Phys. Rev. **D60**, 072002 (1999).

[63] B. Abbott et al., Limits on anomalous $WW\gamma$ and $WWZ$ couplings from $WW/WZ \to e\nu jj$ production, Phys. Rev. **D62**, 052005 (2000).

[64] B. Abbott et al., Extraction of the width of the W boson from measurements of $\sigma(p\bar{p} \to W + X) \times B(W \to e\nu)$ and $\sigma(p\bar{p} \to Z + X) \times B(Z \to ee)$ and their ratio, Phys. Rev. **D61**, 072001 (2000).

[65] V. Abramov et al., Fast scintillation counters for the D0 muon system upgrade, IEEE Trans. Nucl. Sci. **46**, 865–868 (1999).

[66] N. Parashar et al., Real-Time Data Processing in the Muon System of the D0 Detector, IEEE Trans. Nucl. Sci. **47**, 276–279 (2000).

[67] Y. Musienko et al., Radiation hardness of avalanche photodiodes using californium-252, Proceedings of the Fourth Workshop on Electronics for LHC Experiments (LEB 98), Rome, Italy, 21-25 Sep 1998.

[68] J. Moromisato et al., Novel electronic sensors at CMS, Proceedings of the Fourth Workshop on Electronics for LHC Experiments (LEB 98), Rome, Italy, 21-25 Sep 1998.

[69] S. Baccaro et al., Radiation damage effect on avalanche photodiodes, Nucl. Instrum. Meth. **A426**, 206–211 (1999).

[70] A. Karar, J. C. Vanel, and Y. Musienko, Characterization of avalanche photodiodes for calorimetry applications, Nucl. Instrum. Meth. **A428**, 413–431 (1999).

[71] B. Patel et al., Avalanche photodiodes for the CMS electromagnetic calorimeter, Proceedings of the 5th Workshop on Electronics for the LHC Experiments (LEB 99), Snowmass, Colorado, 20-24 Sep 1999.

[72] K. Deiters et al., Properties of the most recent avalanche photodiodes for the CMS electromagnetic calorimeter, Nucl. Instrum. Meth. **A442**, 193–197 (2000).

[73] K. Deiters et al., Investigation of the avalanche photodiodes for the CMS electromagnetic calorimeter operated at high gain, Nucl. Instrum. Meth. **A461**, 574–576 (2001).

[74] Y. Musienko, S. Reucroft, and J. Swain, A simple model of EG&G reverse reach-through APDs, Nucl. Instrum. Meth. **A442**, 179–186 (2000).

[75] E. Auffray et al., Beam tests of lead tungstate crystal matrices and a silicon strip preshower detector for the CMS electromagnetic calorimeter, Nucl. Instrum. Meth. **A412**, 223–237 (1998).

[76] J. Moromisato et al., Study of position resolution with COPS, Nucl. Instrum. Meth. **A426**, 375–384 (1999).

[77] G. Alverson and L. Taylor, The CMS Event Display (CMSCAN Classic), in *Proceedings of the HEPVIS98 Workshop*, edited by A. Johnson, Stanford Linear Accelerator Center, Stanford, 28-30 January 1998.

[78] H. Newman and L. Taylor, "New Computing Challenges for US High Energy Physics", White Paper on US-CMS Software and Computing, 1 Aug 1998, presented to DoE and NSF, Washington D.C., 11 Aug 1998.

[79] J. Bunn, H. Newman and L. Taylor, "US-CMS Participation in Common Software and Computing Projects", 26 October, 1998.

[80] "US-ATLAS and US-CMS Software and Computing Plans for 1999", A joint executive summary prepared by the US-ATLAS and US-CMS Software and Computing groups, 4 Nov 1998.

[81] L. Price, L. Taylor, and others, Brief Summary of the "Status Report of the ICFA Networking Task Force", **ICFA/98/672**, July 1998. `http://nicewww.cern.ch/~davidw/icfa/july98summary.html`.

[82] L. Price, L. Taylor, and others, Status Report of the ICFA Networking Task Force, **ICFA/98/671**, July 1998. `http://nicewww.cern.ch/~davidw/icfa/july98report.html`.

[83] L. Taylor and D. O. Williams, "On the Use of Satellite Television in High Energy Physics", Proceedings of CHEP'98, Chicago, Aug 31 - Sept 4, 1998, **hep-ex/9810039**.

[84] G. Barrand *et al.*, "Status of the HEPVis Class Librarys" CHEP'98, Chicago, Aug 31 - Sept 4, 1998.

[85] G. Alverson, A. Boehnlein, J. Boudreau, X. Fan, I. Gaponenko, J. Kallenbach, L. Taylor, "The HEPVIS Class Library", *Proc. of HEPVIS 98*, SLAC, Stanford, USA, 28-30 January 1998, in press.

[86] G. Alverson,"OpenInventor and NT Experiences" *Proc. of HEPVIS 98*, SLAC, Stanford, USA, 28-30 January 1998, in press.

[87] G. Alverson (on behalf of the HEPVis group), Summary of the HEPVis'01 Workshop, in *Proceedings of CHEP 2001*, edited by H. Chen, Beijing, P.R. China, 3-7 September 2001.

[88] L. Taylor, Plenary summary of: Data Analysis and Visualisation, in *Proceedings of CHEP 2001*, edited by H. Chen, Beijing, P.R. China, 3-7 September 2001.

[89] G. Bagliesi et al., Object-Oriented Reconstruction for CMS Analysis, CMS Note **1999/001** (15 Jan 1999).

[90] I. Osborne, with S. Ashby, J. Wellisch, C. Williams, Code Organisation and Configuration Management, in *Proceedings of CHEP 2001*, edited by H. Chen, Beijing, P.R. China, 3-7 September 2001.

[91] L. Taylor and L. Tuura, Ignominy: a Tool for Software Dependency and Metric Analysis with Examples from Large HEP Packages, in *Proceedings of CHEP 2001*, edited by H. Chen, Beijing, P.R. China, 3-7 September 2001.

[92] J. Wellisch and L. Tuura, Re-usable Templates for Documenting the Elaboration and Architectural Design of the CMS Software, in *Proceedings of CHEP 2001*, edited by H. Chen, Beijing, P.R. China, 3-7 September 2001.

[93] S. Reucroft and J. Swain, patent disclosure to NU patent committee, June 1998.

[94] S. Reucroft, J. Swain, L. Ferrier, and T. O'Neil-Pirozzi, patent disclosure to NU patent committee, June 1998.

[95] J. Swain, and L. Taylor, Numerical Construction of Likelihood Distributions and the Propagation of Errors, Nucl. Instr. and Meth. **A 411**, 153 (1998).

[96] NSF Research Experiences for Undergraduates Program, Grant PHY0097391 `http://www.nsf.gov/home/crssprgm/reu/`.

[97] NSF Research Experiences for Teachers Program, funded as a supplement to REU Grant PHY0097391.

[98] `http://quarknet.fnal.gov/` .

[99] S. Reucroft and J. Swain, Weekly column "*Science Briefs*", The Boston Globe, Science Section, Mondays since Oct. 1997.

[100] "Ask Dr. Knowledge", weekly column in the Boston Globe and other selected papers.

[101] `http://www.sciam.com/askexpert/` .

[102] `http://www.newscientist.com/lastword /answers/676food.jsp?tp=food1`.

[103] "En Busca del Origen de la Masa", Ciencia Hoy (Argentina), Julio/Agosto 1998, available online at `http://www.cienciahoy.org/hoy47/masa01.htm` .

[104] C. Waite, with T. Paul, L. Taylor, Art display for the *Millenium 2000* project, presented in Bonn, Germany, Jan. 1, 2000.

# Biographical Sketches

# GEORGE ALVERSON

*Biographical Sketch*


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### Professional Preparation

| | | | |
|---|---|---|---|
| California Institute of Technology | Physics/English | B.S. | 1973 |
| University of Illinois at Urbana-Champaign | Physics | M.S. | 1974 |
| University of Illinois at Urbana-Champaign | Physics | Ph.D. | 1979 |
| University of Illinois at Urbana-Champaign | Physics | Post-doc | 1979-1982 |

### Appointments

| | |
|---|---|
| 1989-present | Associate Professor, Northeastern University |
| 1996-1997 | Unpaid Associate, CERN |
| 1990-1991 | Unpaid Associate, CERN |
| 1987-1988 | Visiting Scientist, Fermilab |
| 1982-1989 | Assistant Professor, Northeastern University |
| 1981-1982 | Visiting Research Assistant Professor, University of Illinois |
| 1979-1981 | Research Associate, University of Illinois at Urbana-Champaign |
| 1979 | Applications Analyst, McDonnell Douglas Electronics |
| 1974-1979 | Research Assistant, University of Illinois |
| 1973-1974 | University Fellow, University of Illinois |

### Selected Publications

- G. Alverson. Summary of the HEPVis 9201 Workshop. In *Proceedings of CHEP 2001*, Beijing, P.R. China, 3-7 September, 2001.
- G. Alverson, I. Osborne, L. Taylor, and L. Tuura. The IGUANA Interactive Graphics Toolkit with Examples from CMS and DØ. In *Proceedings of CHEP 2001*, Beijing, P.R. China, 3-7 September, 2001.
- G. Alverson. OpenInventor and NT Experiences. In *Proceedings of HEPVIS 98*, SLAC, Stanford, USA, 28-30 January, 1998. To be published.
- G. Alverson et al. The Hepvis Class Library for Event Visualization. In *Proceedings of the CHEP'97 Conference*, Berlin, Germany, April 7-11 1997.
- G. Alverson and L. Taylor. Interactive graphics for the CMS experiment at the LHC. *CMS Technical Note*, 95-172, 1995.
- ALEPH, DELPHI, L3, and Opal Collaborations. Electroweak Parameters of the $Z^0$ Resonance and the Standard Model. *Physics Letters B*, 276:247–253, 1992. CERN PPE/91-232.
- G. Alverson et al. Production of Direct Photons and Neutral Mesons at Large Transverse Momenta by $\pi^-$ and $p$ beams at 500-GeV/c. *Phys. Rev.*, D48:5–28, 1993.

- G. Alverson et al. Direct Photon Production at High-$p_T$ in $\pi^-$-Be and pBe Collisions at 500 GeV/c. *Physical Review Letters*, 68:2584–2587, 1992.

**Synergistic Activities**

Alverson has been active in giving technical advice and aid to various local efforts, including publication and web design for the *Melrose Alliance Against Violence,* pulling cables for NetDay at the local schools and writing an occasional column for the local newspaper.

**Collaborators**

Members of FNAL E-706, L3, DØ and CMS Collaborations.

**Graduate and Postdoctoral Advisors**

- PhD Thesis Advisor: Lee Holloway, University of Illinois at Urbana-Champaign
- Post Doctoral Advisor: Lee Holloway, University of Illinois at Urbana-Champaign

**Thesis Advisor and Postgraduate-Scholar Sponsor**

- C. Lirakis, C. Yosef (2 PhD students)

# STEPHEN REUCROFT

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**Professional Preparation**

| | | | |
|---|---|---|---|
| Liverpool University | Physics | B.Sc. | 1965 |
| Liverpool University | Particle Physics | Ph.D. | 1969 |
| CERN | Particle Physics | Post-doc | 1969-1973 |

**Appointments**

| | |
|---|---|
| 1992-present | Matthews Distinguished University Professor |
| 1986-present | Professor of Physics, Northeastern University |
| 1988-1993 | Chair, Physics Department, Northeastern University |
| 1986 | Associate Professor of Physics, Northeastern University |
| 1982-1987 | EP Division Group Leader, CERN, Geneva |
| 1979-1986 | Staff Physicist, CERN, Geneva |
| 1978 | Scientific Associate, CERN, Geneva |
| 1977 | Staff Scientist, Max-Planck-Institut, Munich |
| 1973-1979 | Assistant Professor, Vanderbilt University, Nashville |
| 1971-1973 | Research Associate (at CERN), Vanderbilt University, Nashville |
| 1969-1971 | Research Fellow, CERN, Geneva |
| 1967-1969 | Demonstrator, Liverpool University |

**Selected Publications**

- L. A. Anchordoqui, T. P. McCauley, T. Paul, S. Reucroft, J. D. Swain and L. Taylor, *Simulation of water Cerenkov detectors using GEANT4.* Nucl. Phys. Proc. Suppl. 97, 196 (2001) [astro-ph/0006142].
- P. Achard, S. Reucroft et al. *Standard Model Higgs Boson With The L3 Experiment At LEP.* CERN-EP-2001-049. Submitted to Phys. Lett. (2001) [hep-ex/0107054].
- K. Deiters, S. Reucroft et al., *Properties of the avalanche photodiodes for the CMS electromagnetic calorimeter.* Nucl. Instrum. Meth. A 453, 223 (2000).
- J. Moromisato, S. Reucroft et al., *A totally transparent alignment sensor.* Nucl. Phys. Proc. Suppl. 78, 259 (1999).
- B. Abbott, S. Reucroft et al. *Limits on quark compositeness from high-energy jets in anti-p p collisions at 1.8-TeV.* Phys. Rev. D 62, 031101 (2000) [hep-ex/9912023].
- B. Abbott, S. Reucroft, et al., *A Measurement of the W boson mass.* Phys.Rev.Lett.80:3008,1998.

- M. Acciarri, S. Reucroft, et al., *Measurements of mass, width and gauge couplings of the $W^{\pm}$ boson at LEP.* Phys. Lett. B413 (1998) 176-179.
- S. Abachi, S. Reucroft et al., *Observation of the top quark*, Phys. Rev. Lett.**74** (1995) 2632.
- M. Acciarri, S. Reucroft, et al., *Measurement of cross sections and leptonic forward-backward asymmetries at the $Z^0$ pole and determination of electroweak parameters.* Z. Phys. C62: 551-573, 1994.
- O. Adriani, S. Reucroft, et al., *Measurement of the average lifetime of b-hadrons.* Phys. Lett. B317: 474-484,1993.

**Synergistic Activities**

Reucroft is an elected member of the National Association of Science Writers. As a free-lance journalist, he writes a weekly syndicated column for the Boston Globe. He has been a frequent guest on the nationally syndicated talk radio "David Brudnoy Show", where he answers science questions from the general public. He has done interdisciplinary collaborative work with faculty from the Colleges of Engineering and Computer Science and the Department of Speech Pathology at Northeastern University, and he has collaborated with several small businesses around the nation.

**Collaborators**

Members of DØ , L3, PAO and CMS Collaborations.

**Graduate and Postdoctoral Advisors**

- PhD thesis advisor: W. H. Evans (deceased), Liverpool University.
- Postdoctoral Advisor: L. Montanet, CERN.

**Thesis Advisor and Postgraduate-Scholar Sponsor**

- S. Doulas, T. McCauley, S. Villa and J. Gonzalez (graduate students from a career total of 9).
- L. Anchordoqui, J. Moromisato, Y. Musienko, N. Parashar, T. Paul, D. Ruuska, and L. Taylor (post-docs from a career total of 30).

# JOHN D. SWAIN

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### Professional Preparation

| | | | |
|---|---|---|---|
| University of Toronto | Physics and Computer Science | B.Sc.(both) | 1985 |
| University of Toronto | Physics | M.Sc. | 1986 |
| University of Toronto | Particle Physics | Ph.D. | 1990 |
| CERN/World Laboratory | Particle Physics | Post Doc. | 1990-1993 |
| CERN/Northeastern University | Particle Physics | Post Doc. | 1993-1995 |

### Appointments

| | |
|---|---|
| 2000-present | Associate Professor of Physics, Northeastern University |
| 1995-2000 | Assistant Professor of Physics, Northeastern University |
| Nov. 1998 | Visiting Professor of Physics, Universidad Nacional de La Plata, Argentina |
| Oct. 1997 | Visiting Professor of Physics, Universidad Simon Bolivar, Caracas, Venezuela |
| 1996-1998 | ICTP (Trieste, Italy) Visiting Scholar, Universidad Nacional de La Plata, Argentina |
| Nov. 1994 | Visiting Professor of Physics, Universidad Nacional de La Plata, Argentina |
| 1993-1994 | Research Associate, L3 Experiment, CERN (Geneva) |
| 1990-1993 | Instructor, World Laboratory Project, L3/CERN (Geneva) |

### Selected Publications

- M.T. Dova, J. Swain, et al. *A Depression before a Bump in the Highest Energy Cosmic Ray Spectrum*, Phys. Rev. **D57** (1998) 7103
- S. S. Gau et al. *Radiative Tau Lepton Pair Production as a Probe of Anomalous Electromagnetic Couplings of the Tau*, Nucl. Phys. **B523** (1998) 439.
- M.Acciarri et al. *Measurement of the anomalous magnetic and electric dipole moments of the tau lepton*, Phys. Lett. **B434** (1998) 169.
- J. Swain and L. Taylor, *First Determination of the Quark Mixing Matrix Element $V_{tb}$ Independent of Assumptions of Unitarity*, Phys. Rev. **D58** (1998) 093006.
- L. A. Anchordoqui, T. P. McCauley, T. Paul, S. Reucroft, J. D. Swain and L. Taylor, *Simulation of water Cerenkov detectors using GEANT4.* Nucl. Phys. Proc. Suppl. 97, 196 (2001) [astro-ph/0006142].
- K. Deiters, J. Swain et al., *Properties of the avalanche photodiodes for the CMS electromagnetic calorimeter.* Nucl. Instrum. Meth. A 453, 223 (2000).

- Y. Musienko, S. Reucroft, and J. Swain, *A Simple Model of EG&G Reverse Reach-Through APD's*, Proceedings of the Second Conference on New Developments in Photo-detection, Beaune, France, June 1999, Nucl. Instrum. Meth. **A442** (2000) 179.
- M. Acciarri, J. Swain, et al., *Measurements of mass, width and gauge couplings of the $W^{\pm}$ boson at LEP.* Phys. Lett. B413 (1998) 176-179.
- M. Acciarri, J. Swain, et al., *Measurement of cross sections and leptonic forward-backward asymmetries at the $Z^0$ pole and determination of electroweak parameters.* Z. Phys. C62: 551-573, 1994.

**Synergistic Activities**

Swain is very active in outreach and education programs. An elected member of the National Association of Science Writers. As a free-lance journalist, he writes a weekly syndicated column for the Boston Globe. He is a frequent guest on the nationally syndicated talk radio "David Brudnoy Show", where he answers science questions from the general public and has appeared regularly on the Discovery Channel in Canada for the last couple of years. He is now also appearing in the US on Discovery Science. He has lectured widely in Latin America, and written for the popular press in Spanish. He has done interdisciplinary collaborative work with faculty from the Colleges of Engineering and Computer Science and the Department of Speech Pathology at Northeastern University. He has collaborated extensively with industry in the US and abroad.

**Collaborators**

Members of L3, PAO and CMS Collaborations.

**Graduate and Postdoctoral Advisors**

- PhD thesis advisor: R. S. Orr, Toronto University.
- Postdoctoral Advisor: A. Zichichi, CERN.

**Thesis Advisor and Postgraduate-Scholar Sponsor**

- T. McCauley, J. Gonzalez, S. Villa (graduate students from a career total of 5).
- L. Anchordoqui, A. Kuznetsov, Y. Musienko, T. Paul, and L. Taylor.

# LUCAS TAYLOR

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### Professional Preparation

| | | | |
|---|---|---|---|
| Bristol University | Physics | B.Sc. (First) | 1986 |
| Imperial College, London | Particle Physics | M.Sc. | 1987 |
| Imperial College, London | Particle Physics | Ph.D. | 1990 |

### Appointments

<u>Physics</u>:

| | |
|---|---|
| 1993–present | Adjunct Assistant Professor, Northeastern University |
| 1990–present | Research Scientist, Northeastern University |
| 1987–present | Scientific Associate, CERN (unpaid) |
| 1991–2000 | Executive Committee member for L3 experiment |
| Oct–Nov. 1995 | Visiting Professor of Physics, Universidad Nacional de La Plata, Argentina |

<u>Computing (for Physics)</u>:

| | |
|---|---|
| 2000–present | Technical Coordinator for “CMS Software and Computing” Project |
| 2000–present | Deputy Project Manager for “US-CMS Software and Computing” |
| 1998–2000 | Project Manager for “US-CMS Core Applications Software” |
| 1997–1999 | Chair, US-CMS Software and Computing Board |
| 1997–2000 | CMS representative to CERN “Forum on Computing Users and Services” |
| 1996–present | Member of CMS Software and Computing Management Board |
| 1996–present | Member of CMS Software and Computing Technical Board |

### Selected Publications

- L. Taylor, *Plenary summary of: Data Analysis and Visualisation*, in *Proceedings of CHEP 2001*, edited by H. Chen, Beijing, P.R. China, 3-7 September 2001.
- G. Alverson, I. Osborne, L. Taylor, L. Tuura, *The IGUANA Interactive Graphics Toolkit with Examples from CMS and DØ*, in *Proceedings of CHEP 2001*, edited by H. Chen, Beijing, P.R. China, 3-7 September 2001.
- J. Swain and L. Taylor, *First Determination of the Quark Mixing Matrix $V_{tb}$ from Electroweak Corrections to Z Decays*, Phys. Rev. **D58** (1998) 093006.

- M.T. Dova, J. Swain and L. Taylor, *Anomalous charged current couplings of the tau and implications for tau compositeness and two-Higgs doublet models*, Phys. Rev. **D58** 015005 (1998).

- S.S. Gau, T. Paul, J. Swain, L. Taylor, *Radiative Tau Lepton Pair Production as a Probe of Anomalous Electromagnetic Couplings of the Tau*, Nucl. Phys. **B523** (1998) 439.

- L. Taylor (with the L3 Collab.), *Measurement of the Anomalous Magnetic and Electric Dipole Moments of the Tau Lepton*, Phys. Lett. **B434** (1998) 169.

- J. Swain and L. Taylor, *Constraints on the $\tau$ neutrino mass and mixing from precise measurements of $\tau$ decay rates*, Phys. Rev. **D55** R1 (1997).

- L. Taylor (with the L3 Collab.), *Search for neutral B meson decays to two charged leptons*, Phys. Lett. **B391**, 474 (1997).

- L. Taylor (with the L3 Collab.), *Upsilon production in Z decays*, Phys. Lett. **B413**, 167 (1997).

- L. Taylor (with the L3 Collab.), *Search for* $\mathrm{B_d^0} \rightarrow \gamma\gamma$ *and* $\mathrm{B_s^0} \rightarrow \gamma\gamma$ *Decays in Hadronic Z Events*, Phys. Lett. **B363**, 137 (1995).

- L. Taylor (with the L3 Collab.) *Measurement of the average lifetime of b-hadrons.* Phys. Lett. B317: 474-484,1993.

**Synergistic Activities**

Taylor has worked closely with the CERN press and public relations offices to help disseminate the excitement of High Energy Physics to the general public. His graphics representations of HEP events have graced the front pages of numerous international newspapers and magazines, CERN T-shirts, watches, and other PR material and have even been featured as one of the central art exhibits of the Millennium exhibition in Bonn.

He also evaluated the potential exploitation of satellite television broadcasting systems for global data transfer, communications, and interactive distance learning. To help the HEP community anticipate and prepare for the current and future challenges of large highly-distributed collaborations and computing facilities, Taylor participated in the ICFA Networking Task force to evaluate future HEP networking requirements and technologies. Subsequently, he helped negotiate educational network connections between the USA and a number of Latin American countries, in particular Argentina.

**Collaborators**

Members of CMS, L3, and Auger Collaborations and the CERN and Fermilab Computing Divisions.

**Graduate and Postdoctoral Advisors**

- PhD thesis advisor: T.S. Virdee, Imperial College, London

- Postdoctoral Advisor: S. Reucroft, Northeastern University, Boston

**Graduate students, postdocs, and engineers supervised**

- D. McNally, S. S. Gau, S. Villa (graduate students); S. Goldfarb, T. Paul (postdocs); I. Osborne, L. Tuura (software engineers).

# EBERHARD VON GOELER

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### Professional Preparation

| | | | |
|---|---|---|---|
| Technical University, Darmstadt, Germany | | | 1954 |
| University of Illinois at Urbana-Champaign | Physics | M.S. | 1955 |
| University of Illinois at Urbana-Champaign | Physics | Ph.D. | 1961 |

### Appointments

| | |
|---|---|
| 1973-present | Professor, Northeastern University |
| 1990-1993 | Associato, Firenze University and INFN, Italy |
| 1989-1990 | Associato, Torino University and INFN, Italy |
| 1988-1990 | Adjunct Professor, University of Houston |
| 1980-1981 | Executive Officer, Physics Department, Northeastern University |
| 1978-1979 | Visiting Scientist, Stanford Linear Accelerator Center |
| 1977 | Chair, Organizing Committee, 5th International Experimental Meson Spectroscopy Conference |
| 1971-1972 | Visiting Scientist, Fermi National Accelerator Laboratory |
| 1970 | Visiting Scientist, Brookhaven National Accelerator Laboratory |
| 1967-1968 | Visiting Professor, Hamburg University |
| 1966-1973 | Associate Professor, Northeastern University |
| 1966-1973 | Associate Professor, Northeastern University |
| 1963-1966 | Assistant Professor, Northeastern University |
| 1961-1963 | Research Scientist, DESY, Hamburg, Germany |
| 1960-1961 | Research Associate, University of Illinois at Urbana-Champaign |

### Selected Publications

- J. Moromisato, E. von Goeler, et al.. Study of Position Resolution with COPS. Submitted to Nucl. Instrum. Methods (1998).
- B. Adeva, E. von Goeler, et al., *Spin Asymmetries $A_1$ and Structure Functions $g_1$ of the Proton and the Deuteron from Polarized High Energy Muon Scattering.* Phys. Rev. **D58**, 112001 (1998)
- B. Adeva, E. von Goeler, et al., *Polarized Quark Distributions in the Nucleon from Semi-inclusive Spin Asymmetries.* Phys. Lett. **B420**, 180 (1998).
- B. Aglietta, E. von Goeler, et al., *Muon 'Depth Intensity' Relation Measured by LVD Underground Experiment and Cosmic Ray Muon Spectrum at Sea Level.* Phys. Rev. **D58**, 992005 (1998).
- D. Adams, E. von Goeler, et al., *Spin Structure of the Proton from Polarized Inclusive Deep Inelastic Muon-Proton Scattering.* Phys. Rev. **D56**, 5330 (1997).

- S. Abachi, E. von Goeler, et al., *Observation of the top quark.* Phys. Rev. Lett. **74**, 2632 (1995).
- S. Ash, E. von Goeler, et al., *Precision Measurement of Electroweak Effects in* $e^+e^- \to \mu^+\mu^-$ *at* $\sqrt{s} = 29\,GeV$. Phys. Rev. Lett. **55**, 1831 (1985).
- G. Blanar, E. von Goeler, et al., *Search for Forward Production of Massive States which Decay with Muon Emission.* Phys. Rev. Lett. **38**, 192 (1977).
- D. Bowen, E. von Goeler, et al., *Measurements of the* $A_1^+$ *and* $A_2^-$ *Mass Spectra.* Phys. Rev. Lett. **26**, 1663 (1971).
- J. K. dePagter, E. von Goeler, et al., *Photo-production of Muon Pairs: A Test of Quantum Electrodynamics.* Phys. Rev. Lett. **17**, 767 (1966).

**Collaborators**

Members of the CMS, DØ and SMC Collaborations.

**Graduate and Postdoctoral Advisors**

- PhD Thesis Advisor: Hans Frauenfelder, University of Illinois at Urbana-Champaign
- Post Doctoral Advisor: Hans Frauenfelder, University of Illinois at Urbana-Champaign

**Thesis Advisor and Postgraduate-Scholar Sponsor**

- J. Moromisato

# DARIEN WOOD

*Biographical Sketch*


| | |
|---|---|
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### Professional Preparation

| | | | |
|---|---|---|---|
| Massachusetts Institute of Technology | Physics | B.S. | 1982 |
| Massachusetts Institute of Technology | Mathematics | B.S. | 1982 |
| University of California, Berkeley | Particle Physics | Ph.D. | 1987 |

### Appointments

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|---|---|
| 2001-present | Associate Professor of Physics, Northeastern University |
| 1995-2001 | Assistant Professor of Physics, Northeastern University |
| 1991-1995 | Wilson Fellow, Fermilab, Batavia Illinois |
| 1990-1991 | Chercheur Etranger, LAL Orsay, France |
| 1988-1990 | CERN Fellow, Geneva, Switzerland |

### Selected Publications

- B. Abbott et al., Measurement of the Angular Distribution of Electrons from $W \to e\nu$ Decays Observed in $p\bar{p}$ Collisions at $\sqrt{s} = 1.8$ TeV, *Phys. Rev. D* **63**:072001, 2001.
- B. Abbott et al., A measurement of the W boson mass using electrons at large rapidities, *Phys. Rev. Lett.*, **84**:222, 2000.
- B. Abbott et al., Limits on $WWZ$ and $WW\gamma$ Couplings from $p\bar{p} \to e\nu jj$ at $\sqrt{s} = 1.8$ TeV, *Phys. Rev. Lett.*, **79**:1441, 1997.
- B. Abbott et al., Measurement of the Top Quark Pair Production Cross Section in $p\bar{p}$ Collisions, *Phys. Rev. Lett.*, 79:1203, 1997.
- S. Abachi et al., W and Z Boson Production in $p\bar{p}$ Collisions at $\sqrt{s}$=1.8 TeV, *Phys. Rev. Lett.* **75**:1456, 1995.
- B. Baldin et al, DØ Muon Readout Electronics Design, *IEEE Trans. on Nucl. Sci.* **44**:363, 1997.
- S. Abachi et al., The DØ Detector, *Nucl. Instrum. Meth.* **A338**:185, 1994.
- D.R. Wood, Electron Identification with the UA2 Scintillating Fibre Detector, *Nucl. Instr. and Meth.* **A289**:331, 1990.

### Synergistic Activities

Wood has worked in the development of physics curriculum for first year engineering students, and has worked in the interdisciplinary Master Teachers team sponsored by the General Electric Company. He has been received the physics award for outstanding teaching of first year engineering students at Northeastern. He has also co-lead (with Boston University) the Boston Area QuarkNet Center, where he has organized programs for seventeen local high school teachers to facilitate the introduction of particle physics in high school classes. He has served on the Fermilab Users Executive Committee and is a member of the organizing committee of the Moriond Electroweak conference.

**Collaborators**

Members of Mark II, UA2, and DØ Collaborations.

**Graduate Students and Advisees**

Ph.D. Students: S.-M. Chang (1995-1996), S. Doulas (1998-)
Postdoctoral Associates: O. Bardon (1996-1997), P. Hanlet (1996-1999), N. Parashar (1997-), D. Shpakov (2000-)

**Advisors**

PhD Thesis Advisor: Gerson Goldhaber (U.C. Berkeley)
Postgraduate Advisor: Peter Jenni (CERN)